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(54) **POWER GENERATION SYSTEM AND PACKAGE**

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H02M 7/10 (2006.01)
H05G 1/10 (2006.01)

(52) **U.S. Cl.**
CPC **H02M 7/103** (2013.01); **H01J 35/025** (2013.01); **H05G 1/10** (2013.01)

(58) **Field of Classification Search**
CPC H05G 1/10; H05G 1/06; H05G 1/12; H05G 1/32; H05G 1/20; H05G 1/02; H05G 1/08

See application file for complete search history.

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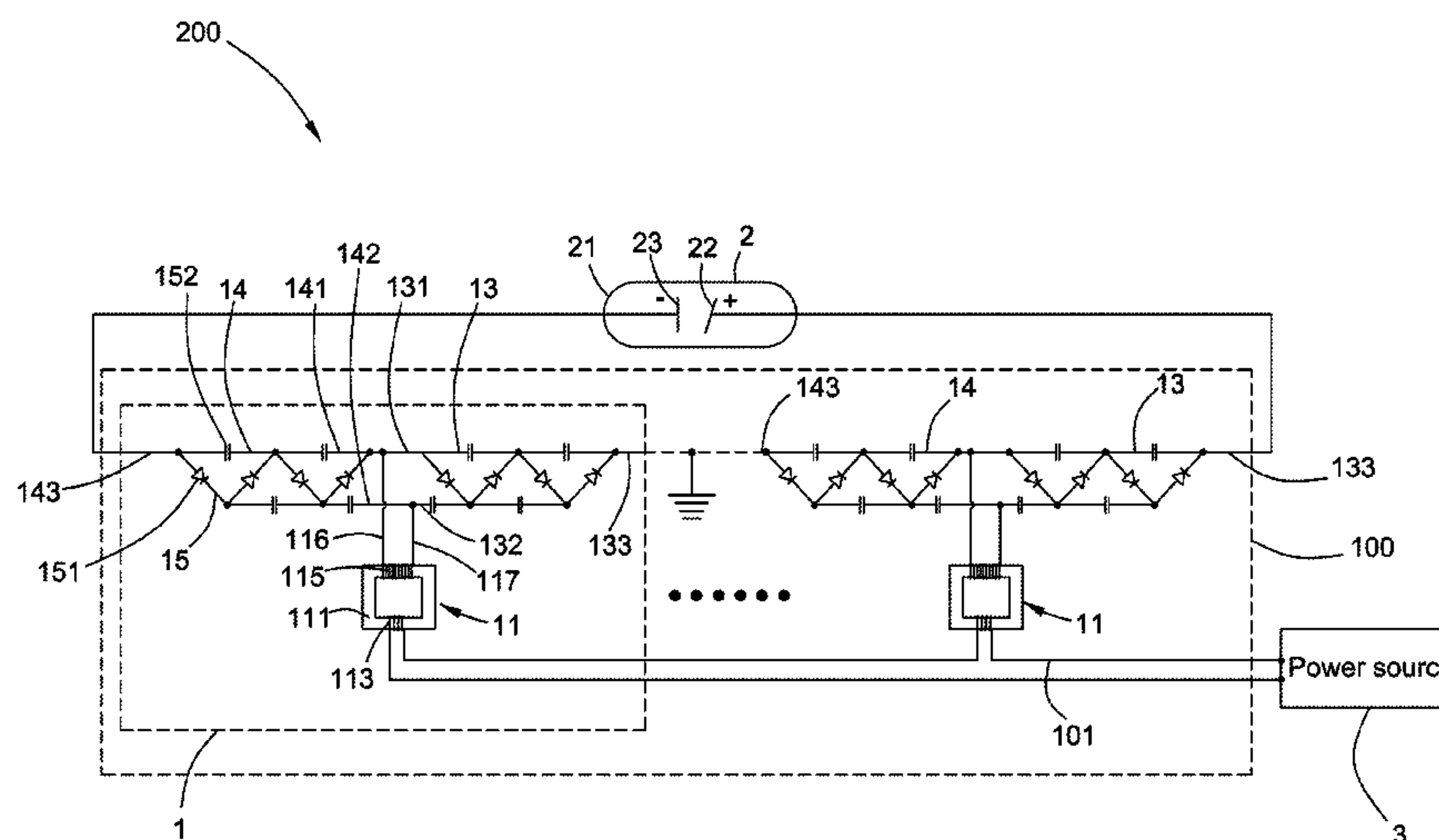
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(57) **ABSTRACT**

A power generation system includes an input to receive a low-voltage alternating current and a number N of voltage-conversion modules coupled to the input, each electrically connected in series. Each voltage-conversion module includes a transformer configured to convert the low-voltage alternating current into a high-voltage alternating current. Each voltage-conversion module includes a multiplier configured to convert the high-voltage alternating current from the transformer into a high-voltage direct current. The multiplier includes a positive multiplier part and a negative multiplier part. The positive multiplier part and the negative multiplier part each includes a pair of input terminals connected in parallel with the transform and at least one multiplier stage comprising a single diode and a capacitor assembly. The number N is an even number between 4 and 24.

8 Claims, 3 Drawing Sheets



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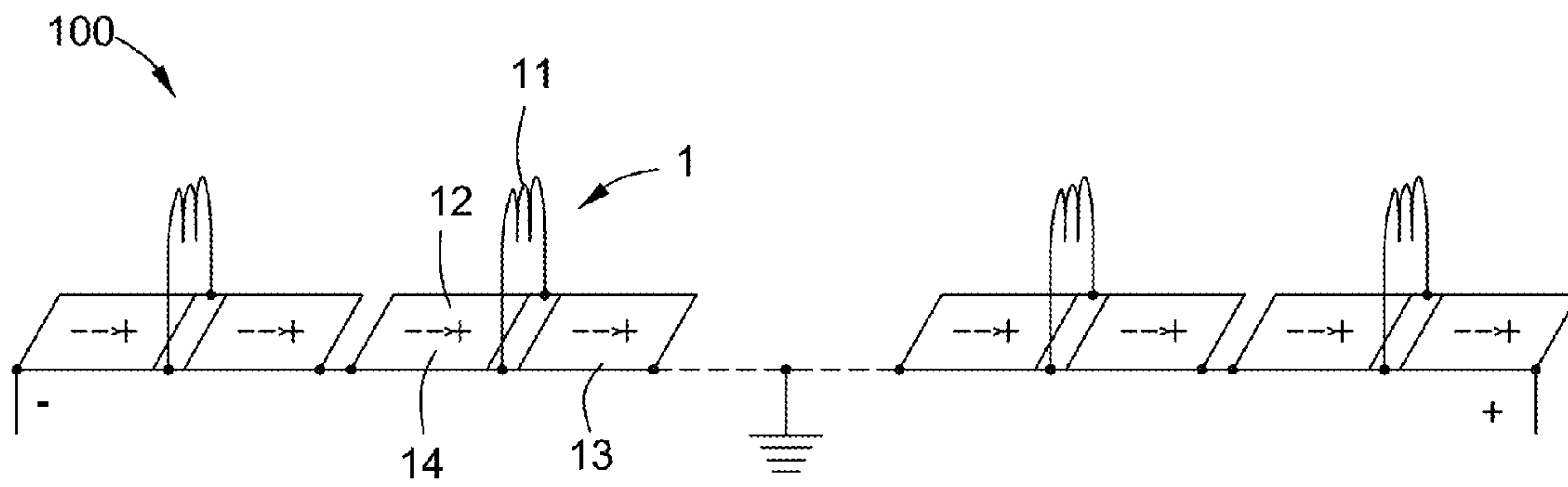


FIG. 1

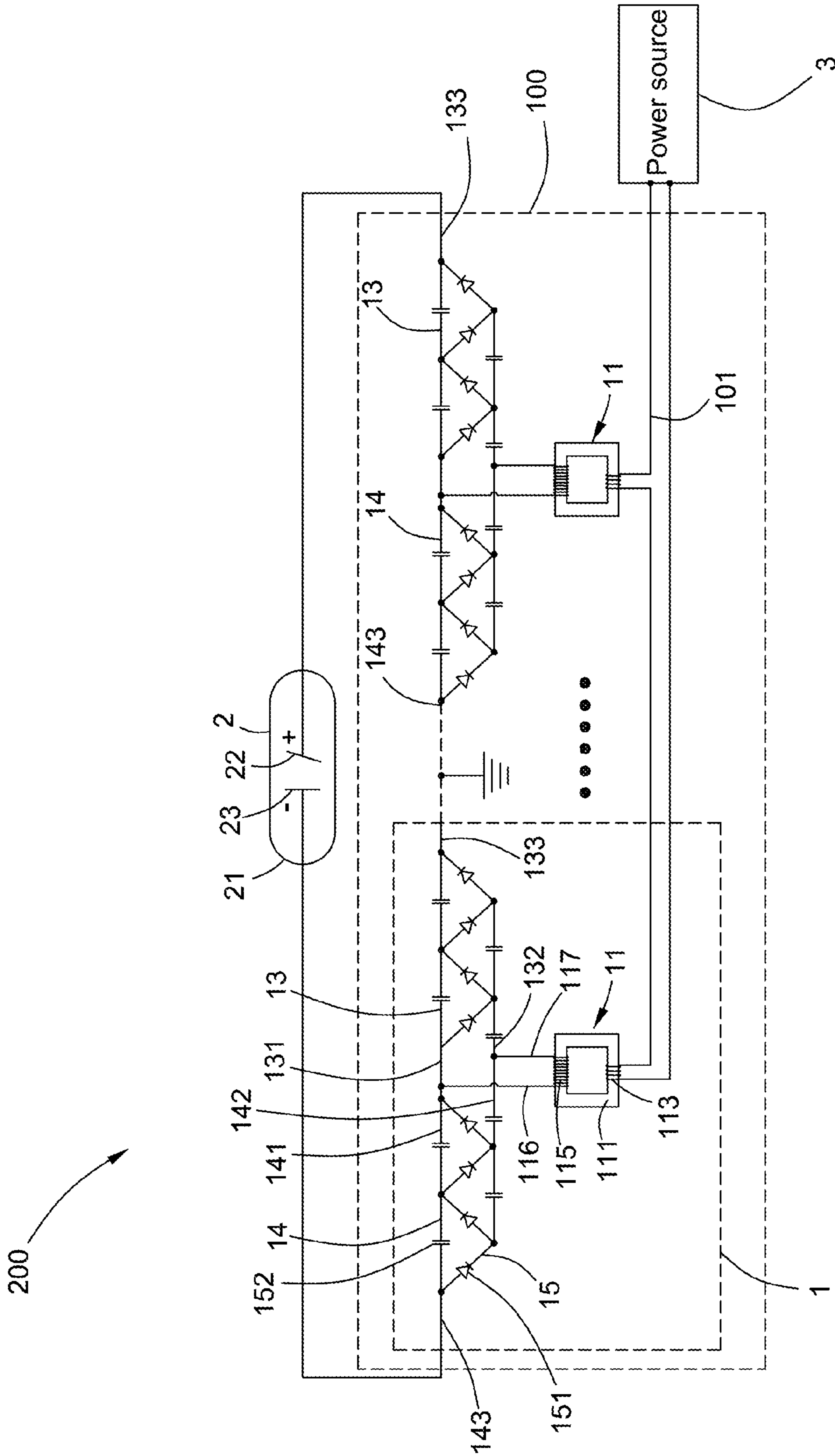


FIG. 2

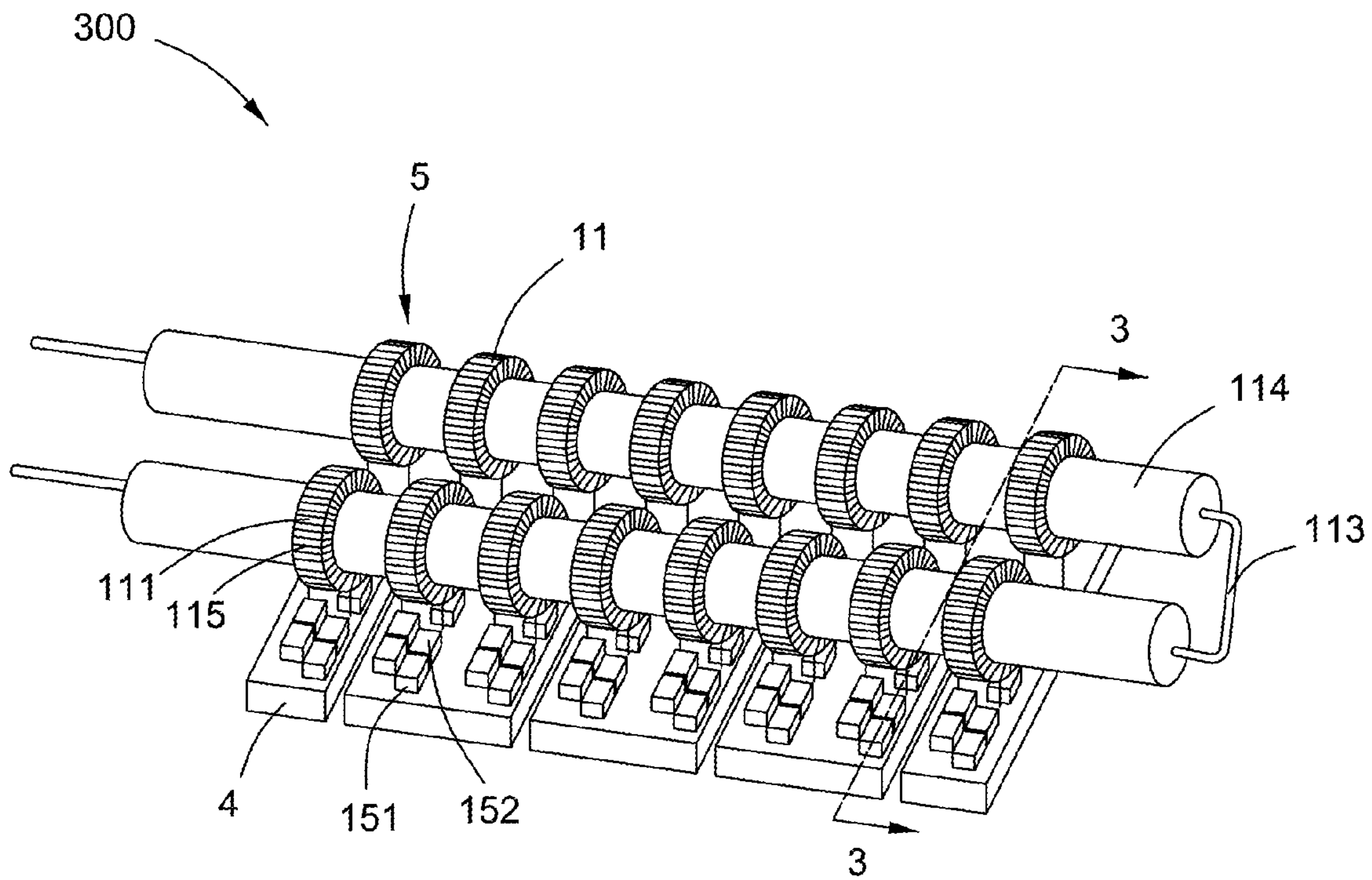


FIG. 3

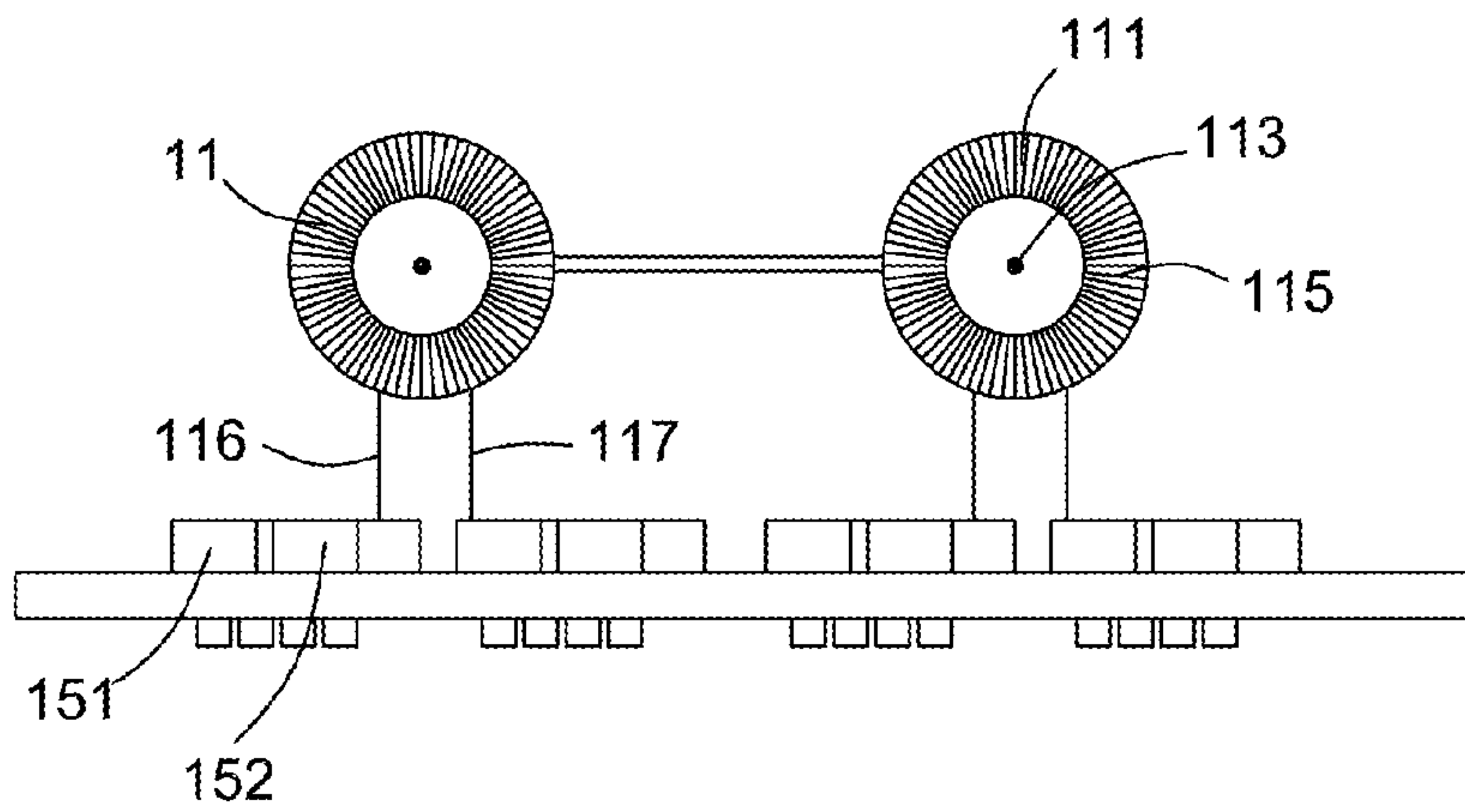


FIG. 4

1

POWER GENERATION SYSTEM AND PACKAGE

BACKGROUND OF THE INVENTION

High-voltage power generation systems are used, for example, for supplying regulated high-voltage direct current (DC) to a vacuum tube, which pushes electrons to flow from a cathode to an anode and generates X-ray emission. The power generation system typically comprises a transformer module which has a high secondary-to-primary turns ratio and converts a relatively low-voltage alternating current (AC) to a relatively high-voltage AC. The power generation system may further comprise a voltage multiplier module which utilizes diodes and capacitors to further boost the high-voltage AC from a secondary winding of the transformer module, as well as to convert the high-voltage AC into the targeted high-voltage DC.

In a conventional power generation system, the transformer module includes at least two transformers and the multiplier module includes at least two multipliers electrically connected in series and each coupled to a corresponding transformer. When the number of the multipliers is too small, in order to achieve a high-voltage DC output, each multiplier must include many diodes of one type coupled in series and capacitors coupled in series, and the capacitors must have large capacitances. The diodes in series exhibit a voltage unbalance effect due to a reverse recovery process of the inconsistent series diodes, and induce over voltage damage. When the number of the multipliers is too large, the multipliers and the transformers need a lot of room, which in turn results in a bulky package and an increased cost.

BRIEF DESCRIPTION OF THE INVENTION

In accordance with an embodiment of the present invention, a power generation system is provided. The power generation system comprises an input to receive a low-voltage alternating current and a number N of voltage-conversion modules coupled to the input, each electrically connected in series. Each voltage-conversion module comprises a transformer configured to convert the low-voltage alternating current into a high-voltage alternating current. Each voltage-conversion module further comprises a multiplier configured to convert the high-voltage alternating current from the transformer into a high-voltage direct current. The multiplier comprises a positive multiplier part, and a negative multiplier part. The positive multiplier part and the negative multiplier part each includes a pair of input terminals connected in parallel with the transform and at least one multiplier stage comprising a single diode and a capacitor assembly. The number N is an even number between 4 and 24.

In accordance with an embodiment of the present invention an X-ray generation system is provided. The X-ray generation system comprises a power source for providing a low-voltage alternating current; an X-ray tube comprising an anode and a cathode; and a power generation system configured to convert the low-voltage alternating current from the power source into a high-voltage direct current supplied to the X-ray tube. The power generation system comprises a number N of voltage-conversion modules electrically connected in series, each of said modules comprising: a transformer coupled to the power source configured to convert the low-voltage alternating current into a high-voltage alternating current; and a multiplier configured to convert the high-voltage alternating current from the transformer into the high-voltage direct current. The multiplier comprises a positive

2

multiplier part and a negative multiplier part, the positive multiplier part and the negative multiplier part each comprising a pair of input terminals connected in parallel with the transform and at least one multiplier stage comprising a single diode and a capacitor assembly. The number N is an even number between 4 and 24.

In accordance with an embodiment of the present invention, a power generation package is provided. The power generation package comprises a printed circuit board carrying a plurality of electronic elements comprising surface mounted diodes and surface mounted capacitors; and a number N of transformers each comprising a core, a primary winding and a secondary winding, wherein the secondary winding is electrically coupled to the electronic elements. The number N is an even number between 4 and 24.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and aspects of the present disclosure will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

FIG. 1 is a schematic diagram of a power generation system in accordance with an embodiment of the present invention;

FIG. 2 is a circuit diagram of an X-ray generation system using the power generation system of FIG. 1;

FIG. 3 is a perspective view of a power generation package in accordance with an embodiment of the present invention; and

FIG. 4 is a cross-sectional view of the power generation package taken along line 3-3 in FIG. 3.

DETAILED DESCRIPTION OF THE INVENTION

Unless defined otherwise, technical and scientific terms used herein have the same meaning as is commonly understood by one of ordinary skill in the art to which this disclosure belongs. The terms "first", "second", and the like, as used herein do not denote any order, quantity, or importance, but rather are used to distinguish one element from another. Also, the terms "a" and "an" do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced items. The use of "including," "comprising" or "having" and variations thereof herein are meant to encompass the items listed thereafter and equivalents thereof as well as additional items. The terms "connected" and "coupled" are not restricted to physical or mechanical connections or couplings, and can include electrical connections or couplings, whether direct or indirect.

Referring to FIG. 1, a power generation system 100 according to an embodiment of the present invention comprises a number N of voltage-conversion modules 1 each electrically connected in series for converting a low-voltage alternating current (AC) into a high-voltage direct current (DC). According to an embodiment of the present invention, the number N is an even number between 4 and 24, including 4 and 24. However, any suitable number of voltage-conversion modules 1 can be used as necessary. Each voltage-conversion module 1 includes a transformer 11 for converting the low-voltage AC into a high-voltage AC and a multiplier 12 electrically coupled to the transformer 11 for further boosting the high-voltage AC from the transformer 11 to an even higher-voltage AC as well as converting the higher-voltage AC into a high-voltage DC.

Referring to FIG. 2, an embodiment of the present invention is shown where the power generation system 100 is used

3

in an X-ray generation system **200** for providing a targeted high-voltage DC to an X-ray tube **2**. The targeted high-voltage DC is a sum of the high-voltage DCs from the voltage-conversion modules **1**. The X-ray tube **2** has a vacuum tube **21**, an anode **22** and a cathode **23** electrically coupled to the power generation system **100**. The targeted high-voltage DC from the power generation system **100** pushes electrons to flow from the cathode **23** to the anode **22** to induce X-ray emission. In certain embodiments of the present invention, the targeted high-voltage DC applied on the anode **22** and the cathode **23** ranges from 40 kV to 160 kV, for example, for medical application, and an X-ray intensity is between 20 mA to 1 A, for example. However, the targeted high-voltage DC can be set to any value as required by the application. The same is true for the X-ray intensity.

The X-ray generation system **200** comprises a power source **3** for providing the low-voltage AC to the transformers **11** of the power generation system **100**. The power generation system **100** comprises an input **101** to receive the low-voltage alternating current from the power source **3**. The power source **3** is an AC power source that can output a lower voltage AC signal. In another embodiment, the power source **3** may include a DC power source and an inverter converting a low-voltage DC from the DC power source to a low-voltage AC. In some embodiments, the power source **3** may further comprise a filtering circuit (not shown). In an embodiment of the present invention, a voltage amplitude of the low-voltage AC of the power source **3** may be about a few hundreds of volts, and a switching frequency of the low-voltage AC from the power source **3** ranges from 100 kHz to 1 MHz, for example. The voltage amplitude and switching frequency can be set as necessary for the application.

With continued reference to FIG. 2, in some embodiments of the present invention, the transformer **11** comprises a core **111**, a primary winding **113** and a secondary winding **115**. The low-voltage AC from the power source **3** is inputted through the primary winding **113**. The core **111** is a ferrite core, a nanocrystalline core or one of other cores. The nanocrystalline core can be used when the switching frequency of the low-voltage AC is around 100 kHz. When the switching frequency of the low-voltage AC is high, such as above 300 kHz, the ferrite core is more preferred. In an embodiment of the invention, the primary windings **113** of the transformers **11** are electrically connected in series. In some embodiments of the invention, the primary windings **113** of the transformers **11** are electrically connected in parallel to the power source **3**. The secondary winding **115** includes a pair of output terminals **116**, **117** through which the high-voltage AC is output. The high-voltage AC output from the transformer **11** ranges from 300 V to 5000 V, for example. However, the high-voltage AC can be set to any value as required by the application.

Referring to FIGS. 1 and 2, each multiplier **12** is a bipolar multiplier and comprises a positive multiplier part **13** and a negative multiplier part **14**. The positive multiplier part **13** and the negative multiplier part **14** each comprise a pair of input terminals **131**, **132**, **141** and **142** connected with the output terminals **116**, **117** of the secondary winding **115** in parallel. The positive multiplier part **13** and the negative multiplier part **14** are each a unidirectional multiplier circuit and respectively rectify and amplify the high-voltage AC output of the transformer **11** into a high-voltage positive DC at a positive DC output **133** and a high-voltage negative DC at a negative DC output **143**. Output terminals **133**, **143** of adjacent multipliers **12** are connected in series, and thus, a total output of the power generation system **100** can be represented as a sum of the output voltages of the multipliers **12** of the

4

voltage-conversion modules **1**. The high-voltage DC output from the multiplier **12** ranges from 1.5 kV to 40 kV, for example. However, the high-voltage DC output from the multiplier **12** can be set to any value as required by the application. In some embodiments, the multipliers **12** have the same voltage input from the transformers **11** and the same DC output.

The positive multiplier part **13** and the negative multiplier part **14** each comprise at least one multiplier stage **15** comprising a single diode **151** and a capacitor assembly **152**. The diode **151** is not easily damaged by an unequal voltage. The diode **151** can be a surface mounted diode with a voltage rating ranging from 600 V to 10 kV, such as 600 V, 1200 V, 3300 V, 6500 V, 10 kV and so on. The capacitor assembly **152** comprises one or more serially connected capacitors and each capacitor is a surface mounted capacitor with a voltage rating ranging from 600 V to 10 kV, such as 600 V, 1200 V, 3300 V, 6500 V, 10 kV and so on. However, the diodes **151** and the capacitors can be other types and set to any value as required by the application. In some embodiments, the number of the multiplier stages **15** in each of the positive multiplier part **13** and the negative multiplier part **14** is between 2 and 8, including 2 and 8. However, the number of the multiplier stages **15** can be set to any value as required by the application.

FIGS. 3 and 4 illustrate a power generation package **300** of the power generation system **100** as described with respect to FIGS. 1 and 2. Referring to FIGS. 3 and 4, the illustrated power generation package **300** comprises a printed circuit board **4** carrying electronic elements **151**, **152** and a transformer module **5** assembled by the number N of the transformers **11**. The electronic elements **151**, **152** include surface mounted diodes **151** and surface mounted capacitors **152** making up the multiplier **12** as described with respect to FIG. 2.

In an embodiment of the invention, the primary windings **113** of the transformers **11** are electrically connected in series and coated by an insulation body **114**. The insulation body **114** is made of polypropylene (PP) or other insulation material to insulate the primary windings **113** from the secondary windings **115**. Each core **111** is ring-shaped and each secondary winding **115** of the transformers **11** winds around each core **111**. The cores **111** encircle the insulation body **114** respectively. The transformer module **5** is located on one side of the printed circuit board **4**. The pair of output terminals **116**, **117** of the secondary winding **115** extend toward the printed circuit board **4** and are electrically connected to the surface mounted diodes **151** and the surface mounted capacitors **152** on the printed circuit board **4**.

The number N of the voltage-conversion modules **1** is optimally determined according to a voltage of the X-ray tube **2** which is the targeted high-voltage DC outputted from the power generation system **100**, a current of the X-ray tube **2**, the switching frequency of the low-voltage AC from the power source **3**, rise and fall speed of the high-voltage DC, as well as voltage ratings of the diodes **151** and the capacitors **152**. As the number of voltage-conversion modules **1** increases, the voltage rating of the diode and capacitor can be decreased. However, the complexity and performance also needs to be considered in balance. The number N is an even number between 4 and 24, so that the X-ray generation system **200** can use diodes and capacitors with low voltage ratings, as well as has a low cost and a compact package. Since the diode has a low voltage rating, the multiplier stage **15** can use only one diode to achieve the desired performance and avoid diode damage resulting from an unbalanced voltage.

5

The higher the switching frequency, the lower capacitance of the capacitor **152** is required. Thereby, the X-ray generation system **200** may use capacitors with lower capacitance. Surface mounted diodes and capacitors have low voltage ratings. So the surface mounted diodes and capacitors can be utilized in the X-ray generation system **200** for thin package. Additionally, the high switching frequency also benefits for high rise and fall speed of the high-voltage DC to reduce X-ray radiation to patients.

While the invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the disclosure. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof.

Furthermore, the skilled artisan will recognize the interchangeability of various features from different embodiments. The various features described, as well as other known equivalents for each feature, can be mixed and matched by one of ordinary skill in this art to construct additional systems and techniques in accordance with principles of this disclosure.

What is claimed is:

1. A power generation system, comprising:

an input to receive a low-voltage alternating current;

a number **N** of voltage-conversion modules electrically coupled to the input, each voltage-conversion module electrically connected together and to the input in series, and each voltage-conversion module comprising:

a transformer configured to convert the low-voltage alternating current into a high-voltage alternating current; and

a multiplier configured to convert the high-voltage alternating current from the transformer into a high-volt-

6

age direct current, the multiplier comprising a positive multiplier part and a negative multiplier part, the positive multiplier part and the negative multiplier part each comprising a pair of input terminals connected in parallel with the transformer, and at least one multiplier stage comprising a single diode and a capacitor assembly;

wherein the number **N** is an even number between 4 and 24.

2. The power generation system of claim **1**, wherein the high-voltage alternating current output from the transformer ranges from 300 V to 5000 V.

3. The power generation system of claim **1**, wherein the high-voltage direct current output from the multiplier ranges from 1.5 kV to 40 kV.

4. The power generation system of claim **1**, wherein the diode is a surface mounted diode with a voltage rating ranging from 600 V to 10 kV.

5. The power generation system of claim **1**, wherein the capacitor assembly comprises one or more serially connected capacitors, wherein each capacitor is a surface mounted capacitor with a voltage rating ranging from 600 V to 10 kV.

6. The power generation system of claim **1**, wherein a switching frequency of the low-voltage alternating current ranges from 100 kHz to 1 MHz.

7. The power generation system of claim **1**, wherein a number of the at least one multiplier stage in each of the positive multiplier part and the negative multiplier part is between 2 and 8.

8. The power generation system of claim **1**, wherein a transformer of one of the number **N** of voltage-conversion modules is connected in series with the input and a transformer of another one of the number **N** of voltage conversion modules.

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